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by

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ABSTRACT

In the one-and-a-half circuit organic nuclear power plant a high and a low boiling point liquid is circulated in the primary and secondary circuit, respectively. As a consequence of the great difference between the boiling points the vapour can be generated in a mixing type steam generator. This paper deals with the construction of a loop for investigating the above type of power plant operating with diphenyl-benzene mixture. The fire, explosion and poisoning danger are taken into account.

KIVONAT

A másfélkörös rendszerü organikus atomerőmüben a primer körben magas forráspontu, a szekunder körben pedig alacsony forráspontu organikus anyag kering. A gőztermelés a forráspontkülönbség következtében keverő hőcserélő tipusu gőzgenerátorban történik. A difenil-benzol elegypárral müködő fenti erőmütipus termodinamikai vizsgálatára létesitett kisérleti berendezést ismertetjük jelen dolgozatban, különös tekintettel a benzol tüz-, robbanás- és mérgezés-veszélyes voltára.

РЕЗЮМЕ

В органической атомной энергетической установке с полуторaконтурной схемой в первичном контуре циркулирует органическое вещество с высокой температурой кипения, а во вторичном контуре с низкой температурой кипения. Вследствие различия в температурах кипения парообразование происходит в парогенераторе смесительно-теплообменного типа.

В настоящей работе мы описываем экспериментальную установку, предназначенную для термодинамического исследования указанного выше типа энергетических установок, работающих на дифенил-бензоловой смеси. Обращаем особое внимание на огнеопасность, взрывную способность и ядовитость бензола.

INTRODUCTION

A basic requirement against cooling agents used in organic nuclear power plants is the high radiolytical and pyrolytical stability. This requirement is satisfied by the various polyphenyls /diphenyl, terphenyl, etc./ and their compounds.

The basic type of the organic nuclear power plant uses one of the above materials as reactor coolant, with the secondary system of a conventional power plant. Such a system has many advantages, but significant problems also arise. One of the most important from the aspects of this paper, is the high melting point of polyphenyls /above room temperature/. So the components of the primary circuit must be heated and this fact will increase the investment cost of this type of nuclear power plant. The heating of the primary system becomes especially problematic if the power plant is intended to be run as an isolated unit, far from the collaborating electrical network.

The disadvantage can be eliminated by the so called "one-and-a-half circuit" system of organic nuclear power plant, where water used in the secondary circuit is substituted by a solvent which forms an eutectic mixture of low freezing point with the polyphenyl of the primary circuit. The primary and secondary circuits are interconnected by a mixing type of heat exchanger providing further advantages.

This paper deals with the construction of the loop built for the investigation of the above one and a half circuit system. Our experimental arrangement is operated under pilot plant conditions, i.e. with parameters /pressure, temperature/ in the expected operational range, but with dimensions which are still rationally realisable in the laboratory.

The pair of agents are diphenyl and benzene. The choice of diphenyl is justified by radiation stability and cost aspects, while that of benzene is unequivocally given partly because in the liquid state it solves the diphenyl unlimitedly and partly because its saturation vapour pressure of 0,1 atm at 20 ^{o}C is a very favourable value for the turbine.

PRINCIPLE OF OPERATION OF THE "ONE-AND-A-HALF CIRCUIT" SYSTEM

The scheme of the nuclear power plant of one and a half circuit system is seen in Fig.1. The principle of operation of this system is as follows:

After filling up with a mixture of desired composition the separation of the components is carried out by satisfactory distillation and so the equipment is ready for the start up. At this moment we have diphenyl of low benzene content in the reactor circuit /in the following "diphenyl circuit"/ and nearly pure benzene in the turbine /in the following "benzene circuit"/. During the operation the benzene is mixed with the diphenyl /heated up in the reactor/ in the steam generator, where a vapour mixture of low diphenyl content is evaporating, whereas the liquid leaving the steam generator is poor in benzene. Actually the system is a continuous distillation equipment. During steady state operation the inlet and outlet concentrations are constant and determined by the equilibrium conditions in the steam generator.

DESCRIPTION OF THE EQUIPMENT

The loop consists of the main elements corresponding to the scheme of the one and a half circuit system shown in Fig.1, completed with the measuring and auxiliary elements. A simplified flow diagram of the equipment is reported in Fig.2. The reactor is substituted by 4 electric heaters, from which the coolant flows through the control valve and is led below the liquid level of the steam generator. The coolant is filtered by sintered metal filters arranged in a by-pass line. The liquid is transferred by two pumps from the steam generator.

The sampling tap is in the cooled by-pass line connecting the suction and the rising tubes of the first pump.

The produced steam is led through a throttle valve into a desuperheater, where it preheats the condensate, then streams to the condenser. The condensate is fed back into the system by two pumps /a condensate and a feed pump/ either through the desuperheater or through a bypass line. There are two possibilities for the feedback: 1./ below the liquid level in the steam generator, 2./ feedback before the control valve in the diphenyl circuit. A special heater is used for the adjustment of the desired temperature of the feed-back benzene.

The non-condensing gases are removed from the condenser by a vacuum pump protected from the benzene by a cool trap. The vapour is sampled from the cooled bypass be tween the fresh-steam line and the condenser.

The charging and discharging is made by nitrogen gas pressure.

DESIGN CONSIDERATIONS

The experimental arrangement had to produce 100 kg/h steam. For determining the effect of the mixing ratio φ (= mass valocity in diphenyl circuit/mass velocity in benzene circuit) the adjustment of values between φ = 10-30 was foreseen, corresponding to a charge of the amount in the diphenyl circuit between 1000-3000 kg/h.

The maximum value of the heater wall temperature was limited so as to avoid a high rate of polymerization and fouling. The maximum value of surface temperature was 420 ^{o}C and accordingly the bulk coolant temperature was limited to 380 ^{o}C.

The operating pressure in the steam generator was 20 ata, but the maximum pressure in the system was limited by the pump to a value of 25 ata at 400^{o}C. So there was a hydraulic head of 5 ata.

SYSTEM COMPONENTS

a/ Heaters

The power input involves the amount of heat necessary for the production of 100 kg/h vapour at 20 ata and of the system heat losses. Corresponding to this requirement the total power input was about 70 kW.

The heaters were constructed with a great liquid volume in order to avoid big transients in the vall temperature in the case of loss of coolant, because the heat capacity of the heaters was great.

The construction of the preheater is identical to the heaters used in diphenyl circuit.

b/ Pumps

Two Worthington-type pumps with artificial carbon shaft-seal was used. The two pumps in series were able to ensure the attainable differential pressure of 5 ata at a liquid temperature of 380 ^{o}C.

c/ Filters

The various impurities occurring in the equipment, were removed by filters of sintered stainless steel of 10 μ. A bypass flow of 10 % for filtration gave suitable results.

d/ Condenser, desuperheater

A condenser with 2 m^2 and a desuperheater with 3 m^2 of heat transfer surface was used to remove the heat of 19000 kcal/h. The condenser pressure was 0,1 ata at 20 ^{o}C.

e/ Condensate and feedpump

For the feedback of the 100 kg/h condensate a Bosch-type charging pump with 14 piston elements and before it an additional booster pump was used. The application of the above pumps was justified by the need for a constant feedback. The pumped quantity could be adjusted with a high accuracy within the desired limits by the variation of the excitation of the d.c. driving motor of the charging pump and the useful stroke length of the piston elements.

INSTRUMENTATION

For the safe operation of the loop and to carry out the experimental program the following 6 quantities had to be measured:

1. Pressure
2. Temperature
3. Flow rate
4. Concentration
5. Electric power
6. Liquid level.

1. The pressure was measured by the Bourdon-tube contact manometers with 0,6 and 1,5 % of accuracy. By the con-

tactors of the contact manometers a safety protection was operated. The manometers in the diphenyl circuit were connected to the measurement points through heatable pressure transmitting devices.

2. The temperature was measured by NiCr-Ni sheated thermocouples and/or platinum resistance thermometers.

3. The measurement of the flow rate was carried out with turbine-flowmeters.

4. The concentration was measured with an ABBE-type refractometer, for which the samples were taken from a cooled bypass line.

5. The electric power was measured by instruments of low accuracy because the exact knowledge of the supplied power was not necessary for the analysis of the measurements.

6. For the liquid level measurement electromechanical level indicators of closed system with floats were used.

SAFETY SYSTEM

Because of the large amounts of benezene administrative and technical measures were applied to avoid fire, explosion and poisoning.

A detailed operational instruction had to be used, including the possible alarm situations. The loop arrangement was placed into a closed box and an intensive air exchange was provided. The maximum values of temperature and pressure was limited by an electronic safety system.

At the same time protection was also provided by mechanically operated safety valves /placed at appropriate points/ against any exaggerated pressure rise. These safety valves exhausted through discharge tanks into the atmosphere.

Putting the individual elements of the arrangement into operation in a wrong sequence was made impossible by interlocking circuits.

SUMMARY

We have built a loop for the thermodynamical investigation of the one-and-a-half circuit system organic nuclear power plant working with diphenyl-benzene mixture. The arrangement had a capacity of 150 l. mixture and was designed to produce 100 kg/h steam. This quantity of steam was not enough to use a turbine in the loop. So it was substituted by a throttle valve and a desuperheater. Because of the high benzene quantity in the loop the arramgement was dangerous in a greater extent. The safety precautions against an accident were effective and suitable, so after the problems of intightness at the beginning of the program the loop operated safely during the experiments.

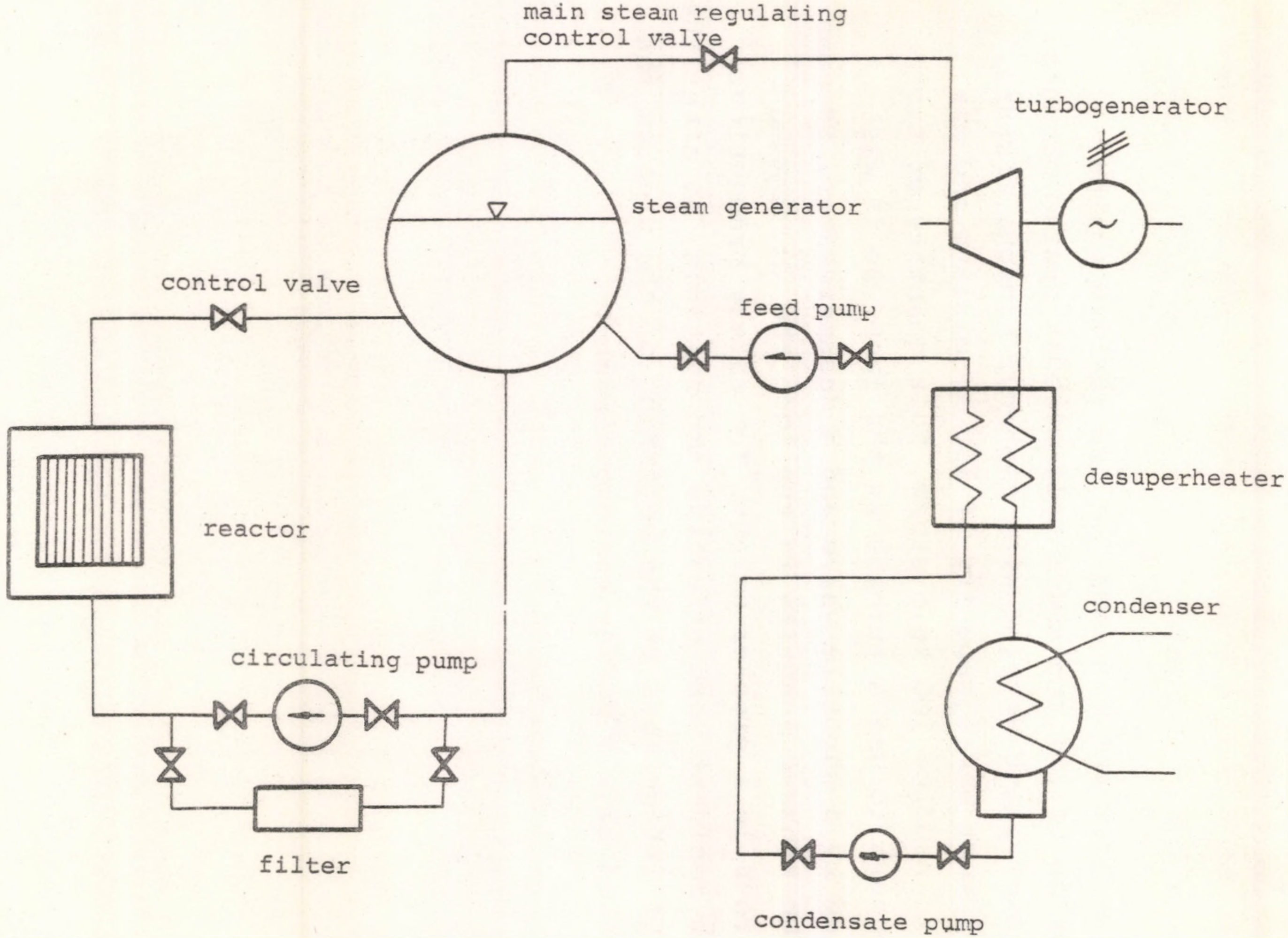
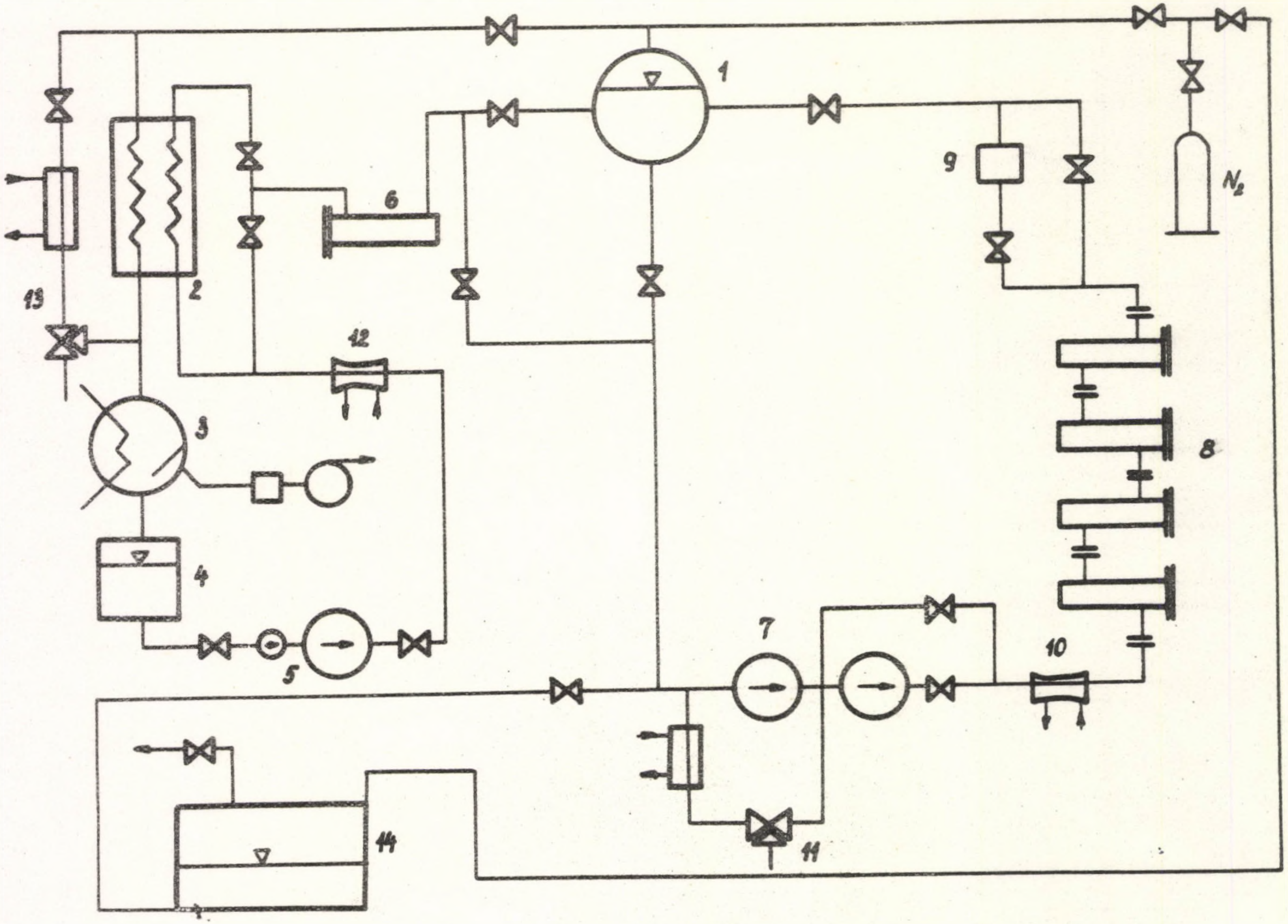


Fig. 1 Schematic of the one-and-a-half circuit organic nuclear power plant



1. Steam generator
2. Desuperheater
3. Condenser
4. Condensate tank
5. Condensate and feed pumps
6. Preheater
7. Circulating pumps
8. Heaters

10,12 Flowmeters

11,13 Sampling

14 Discharge tank

Fig. 2 Flow diagram of the loop

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Kiadja a Központi Fizikai Kutató Intézet
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Készült a KFKI sokszorosító üzemében, Budapest, 1973. március hó